Significance of the suppression of substrate surface nitridation for epitaxial growth of wurtzite InN on GaP(111) and InP(111) substrates

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The limitations of sapphire, such as its insulating property, raise high demand to deposit the III-V nitrides on other suitable semiconductor substrates. III-V arsenides and phosphides have gained importance as an alternative substrate material of sapphire. GaAs is one of the most widely studied III-V substrates. GaP and InP are also suitable III-V semiconductor substrates, having smaller lattice mismatch and closer thermal expansion coefficient with nitride, than that of sapphire. Preferably, lattice mismatch between GaP(111) and InN(0002) is smaller than that between GaAs(111) and InN(0002); 8% for GaP and 11.3% for GaAs. But there have been very few reports on GaP and InP substrates for the growth of InN. In this paper, we report that suppression of the substrate surface nitridation is significant to obtain single crystalline InN films on the phosphide substrates. By suppressing the nitridation, single crystalline InN film with an excellent crystallinity and surface morphology can be grown on a GaP(111)B substrate. Nitridation of InP(111)B occurs considerably at a lower temperature than that of GaP(111)B. However, crystalline quality of InN on InP(111)B can also be improved by reducing the nitridation.

Wafers of GaP(111)B and InP(111)B have been used as a substrate. The substrates were degreased and then etched before loading into the reactor. The substrates were thermally cleaned in the flowing H_2 at 700^0C for GaP(111)B and at 500℃ for InP(111)B after loading into the reactor . Nitridation of the substrates has been made in the flowing NH_3 at a temperature in the range of 500-1000℃. The MOCVD growth of InN was carried out using TMI and NH_3 as source materials and N_2 as a carrier gas at 450-600℃ in a reduced pressure of about 0.1 atm. InN grown films and nitrided surfaces were evaluated with XPS, RHEED and AFM analysis.

To study the nitridation effects of phosphide substrates, for any good effects like GaAs or Sapphire, nitridation of GaP(111)B and InP(111)B has been made in the flowing NH_3 at a different temperature. Figure 1 shows the XPS P_{2p} spectra of GaP(111)B and InP(111)B surfaces exposed to an NH_3 flow at a different temperature. With increasing exposing temperature a new peak of P_{2p} appears at a binding energy of about 133 eV. The position of this new peak of P_{2p} is in good agreement with the P_{2p} peak of the deposited phosphorus-nitride films [1, 2]. From the intensity of the new peak of P_{2p} spectra it is clear that nitridation of InP(111)B surface is strongly happened even at 500℃, where as, nitridation of GaP(111)B happened above 500℃.

Formation of PN_x on the substrate surfaces after nitridation of GaP(111)B carries the tendency of grown InN films to become polycrystalline [3]. Therefore, InN films have been grown on GaP(111)B and InP(111)B without any intentional nitridation of the substrate surfaces. A single crystalline InN film is grown on GaP(111)B at 500℃ as shown in Fig. 2(a). If the growth temperature increases up to 600℃, the InN film quality becomes poor as shown in Fig. 2(b), which is caused by the nitridation of the substrate surfaces during the growth at such temperature. A InN film grown on InP(111)B is inferior to that grown on GaP(111)B, even at 500℃ as shown in Fig. 2(c). This is mainly due to that the nitridation happens strongly on InP(111)B at 500℃ compared with GaP(111)B, as shown in Fig.1.

Generally, a higher growth temperature results in a better crystalline quality of a grown film. In the case of phosphide substrates, however, a higher growth temperature enhances the nitridation of substrate surface during the growth. To suppress the nitridation during the growth of InN on GaP(111)B at 600℃, a low temperature layer of thickness about 20 nm was grown initially at 450°C and temperature was increased from 450 to 600°C during the growth. The total thickness of the grown InN film was about 200 nm. By suppressing nitridation, i.e., growing a low temperature buffer layer, a single crystalline InN film with an excellent crystalline structure is grown on GaP(111)B at 600°C as shown in Fig. 3(a). The streak RHEED pattern of this sample shows the two-dimensional growth of InN on GaP(111)B at 600°C, which is also confirmed by AFM analysis as shown in Fig. 3(b).

In summary, using a conventional MOCVD system growth of InN has been studied on GaP(111)B and InP(111)B substrates. PN_x was formed on the GaP(111)B and InP(111)B substrate surfaces when exposed to NH_3 flow. Epitaxial growth of InN is impeded due to the nitridation of the substrate surfaces, which carries the tendency of grown InN films to become polycrystalline. Suppression of the substrate surface nitridation is found to be significant to obtain single crystalline InN films on GaP(111)B and InP(111)B substrates.

References:

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[2] Y. Matsumoto et al., Proc. 7th Int. Conf. on Indium Phosphide and Related Materials, Sapporo, Japan (1995) p.609.
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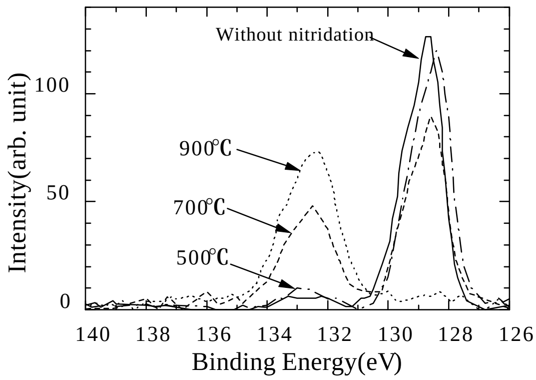


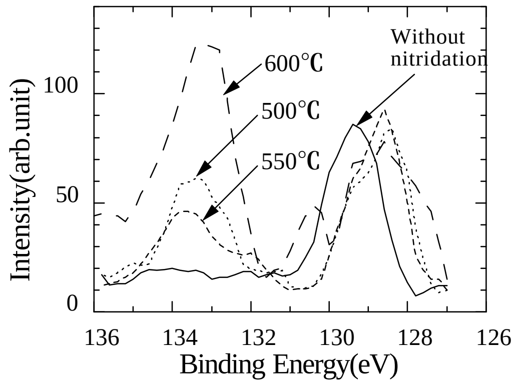
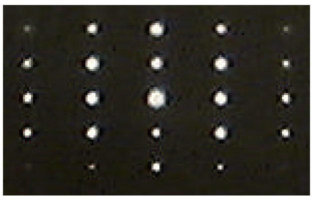
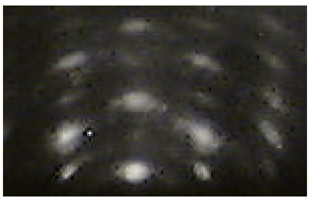


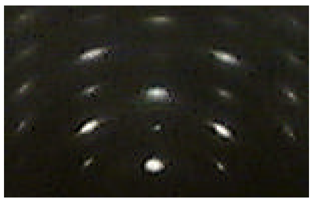
Fig. 1. XPS P_{2p} spectra of GaP(111)B and InP(111)B substrate surfaces nitrided at a different temperature. The intensity was normalized by the Ga_{3d} and In_{3d} peak intensity respectively.



(a) 500^{0}C on GaP(111)B

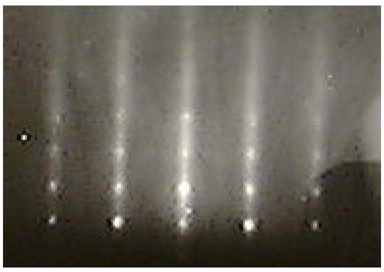


(b) 600^{0}C on GaP(111)B

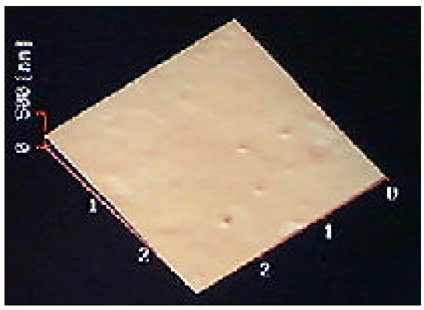


(c) 500^{0}C on InP(111)B

Fig. 2. RHEED patterns of InN films grown on GaP(111)B and InP(111)B. Electron beam parallel to [011] of the



(a) RHEED pattern



(b)AFM image

Fig. 3. RHEED pattern and AFM image for a InN film grown on GaP(111)B at 600°C. A low temperature layer was grown initially at 450°C to suppress the substrate surface nitridation and temperature was increased from 450 to 600°C during the growth.